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A DESIGN DASHBOARD FOR MANAGING GROUNDWATER USE AND SUSTAINING AQUIFER RECHARGE THROUGH VILLAGE-LEVEL INTERVENTIONS

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ABSTRACT

Water scarcity issues have been developing in many parts of the world due to climate change and the new extremes it accompanies. An interactive dashboard has been developed to track these changes within five villages in a northwest district in India to aid in solving the problem of groundwater over-extraction. The design science research method was used to create this dashboard as a design artifact to assist decision-makers, villagers, and other members of the general public on the patterns of their local groundwater. This dashboard can help create new strategies and policies to find and manage groundwater over-extraction.

Keywords (required)  
Design Artifact, Groundwater Management, Water Resources, Dashboard, Visualizations

INTRODUCTION

“Water scarcity affects more than 40 per cent of the global population and is projected to rise. Over 1.7 billion people are currently living in river basins where water use exceeds recharge.” - UN Sustainable Development Goals #6 (2020)

Many scientists believe we have entered a new epoch, the Anthropocene. This new era of human-influenced climate and environment brings a new wave of problems. Water scarcity issues have been developing in many parts of the world due to climate change and the new extremes it accompanies. This problem has led many villages in India that rely on groundwater for vital agricultural use, to continuously drill deeper bores in the ground to attain more groundwater. Since groundwater is a limited resource, a problem arises because the more that groundwater is extracted, the more an aquifer has to recharge. This has guided many people in the community to explore new alternative paths that lead to a more sustainable future for water resource management.

Managing Aquifer Recharge through Village-level Intervention (MARVI) for sustaining groundwater use is a trans-disciplinary research and development project focused on sustainable water management. This study aims to optimize a well-monitoring network, comprising five villages in the Udaipur District of the state of Rajasthan, India to reduce the difficulty for the villagers that monitor these wells on a weekly basis and to reduce the amount of money it takes to do so.

While having fewer wells to monitor conserves time and money, it also comes with other obstacles. One of the obstacles is the problem of how to maintain adequate well monitoring accuracy with a smaller amount of observation points. The MARVI project has also sought out a way to visualize all this groundwater data in an interactive manner so that stakeholders, villagers, and other members of the general public can use the data to gain an understanding of how rainfall and groundwater levels affect the region that these villages are located in. This study aims to address this need by building an interactive dashboard that was built using design science principles (Hevner et al., 2004).
BACKGROUND

Groundwater

Groundwater is a critical and finite resource in numerous parts of the world. The country of India relies on groundwater for 60% of its irrigation water for crops and 80% of its drinking water. Groundwater in India is predominantly recharged during the monsoon season, which lasts from June to September, with the northern parts receiving less rainfall than the southern parts. Some villages have resorted to drilling deeper wells to acquire more water but routinely results in depletion of the aquifer and can lead to a decreasing water supply over time. Aquifers recharge naturally with rainfall over time, but in areas with over-extraction, the pumping rate is greater than the rate of recharge. Satellite-based measurements have detected a ~109km$^3$ decrease in water supply from 2002 to 2008, emblematic of unsustainable water consumption (Rodell, Velicogna, & Famiglietti, 2009).

Predicting groundwater fluctuations has grown in prevalence as global concerns rise over water shortages. While the field is still actively changing, “the most obvious input variables in groundwater level predictions studies are rainfall, evaporation, temperature and pumping patterns” (Yadav et al., 2019). In considering rainfall data, a standard practice is to set up a network of rainfall gauges to collect this data. A similar method was used to collect rainfall data on the Shetrunji river basin, a hard rock aquifer, in Gujarat, an adjacent state directly south of Rajasthan (Patel et al., 2016). Notably, this study as well as several others are focused on determining the optimal number of rainfall gauges as the gauges themselves are expensive and require maintenance, so achieving efficiency is very vital to success. The Kriging error is a commonly used technique to aid in determining optimal placement. It is an interpolation technique that draws its basis from generalized least-square regression methods for geostatistics (Adhikary et al., 2015). An analysis using principal component analysis could be coupled with certain selection criteria to collect rainfall data via weather radar, satellite or other remote sensors allowing data collection without the reliance on expensive rainfall gauge equipment (Dai et al. 2017). This method could allow for cheaper data collection that would be consistent and viable, despite lower accuracy. While this method is not perfect, it holds great potential to reduce costs, involved in rainfall measurements over large areas.

Design Science

The design artifact developed in this study follows the convention of design science research (Hevner et al., 2004). During the process, the research must advance the design process along with the design artifact as a part of the design science research approach. In a project that has the main goal of educating a population that is directly affected by the consequences of water scarcity, there was a need to visualize the problem at hand. The dashboard created in this project demonstrates the different patterns throughout the year and how the different seasons affect groundwater availability in those regions.

METHODOLOGY

Data Sets

The data used in the dashboard was previously collected by Bhujal Jankaars also called “The Groundwater Informed”, these farmers collected groundwater levels on a weekly basis and rainfall amounts also on weekly intervals. The rainfall data and the groundwater level data were both in units of meters (see Table 1 for the data dictionary). In the Dharta watershed, five villages were selected. This data was recorded on an app that is utilized on a smartphone called MyWell that collects the data entered by the Bhujal Jankaars along with the well location. The location data was in a longitude and latitude format. The MyWell app was previously created by the MARVI project to aid in easier data collection and sharing by villagers in these regions. Other parameters included in this data were the well depth of each monitoring well in meters and the elevation of the well in meters. Both of these parameters were used in the Well Explorer visualization.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Data Type</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ground Water Level</td>
<td>Float</td>
<td>m</td>
</tr>
<tr>
<td>Rainfall</td>
<td>Float</td>
<td>m</td>
</tr>
</tbody>
</table>
Table 1. Data Dictionary

<table>
<thead>
<tr>
<th>Elevation</th>
<th>Float</th>
<th>m</th>
</tr>
</thead>
<tbody>
<tr>
<td>Well Depth</td>
<td>Float</td>
<td>m</td>
</tr>
<tr>
<td>Latitude</td>
<td>Geo</td>
<td>X</td>
</tr>
<tr>
<td>Longitude</td>
<td>Geo</td>
<td>Y</td>
</tr>
</tbody>
</table>

Use Cases for Design Artifact

To construct the various visualizations used in the Groundwater Explorer and the Well Explorer, specific use cases (or user stories) were used. For the Groundwater Explorer, the use cases that were to be addressed were:

- What are the patterns of groundwater changes in the wells over time and across villages?
- How are these patterns related to parameters such as rainfall?
- How can we use these patterns to mitigate the problem of over-extraction of groundwater?

For implementing these questions into the design of the Groundwater Explorer dashboard, the dashboard included filters by season, village, month, elevation, water depth, and average groundwater level. This created a way to have a completely customizable dashboard to whatever interests the dashboard user has.

For the Well Explorer, the use cases that were addressed were:

- How do different villages' wells compare to other villages, when looking at well depth?
- How do different villages' wells compare to other villages, when looking at well elevation?

These user stories helped create a dashboard that helped the users gain a more personal connection with the region and farmers.

Design Artifact

The design artifact can be viewed at https://msanalytics.github.io/MARVI/. The visualizations used in the groundwater explorer were created in Tableau and embedded in a github.io repository.

MARVI Groundwater Explorer

Figure 1. Image of MARVI Groundwater Explorer.
The MARVI Groundwater Explorer (see Fig 1) is an interactive tool that users can use to gain a greater understanding of rainfall and groundwater level patterns in these five villages. In the dashboard there are three main modules. The outer left side is the average rainfall by village module. The middle module is a map with each well. The wells are filtered by color for average groundwater level at each well. The outer right module is average groundwater level by village. All three of these modules change when the slider bar filters on the right side are adjusted. This dashboard includes the filters for season, month, well elevation, and well depth.

**MARVI Well Explorer**

![Figure 2. Image of MARVI Well Explorer](image)

The MARVI Well Explorer (see Fig 2) is an interactive tool that users can use to become familiar with the wells in each village. This dashboard shows a map of all the wells, sorted in color by village. When hovering the mouse over each well, all information about the well is shown. This information shows well location coordinates, well depth, well elevation, the village that the well is in, and the name of the farmer whose land the well is on.

**LIMITATIONS**

There were a few sections of groundwater data that had null values that had to be removed from the data set. The format of the data entered through the MyWell app was also hard to work with where each date was on the first row for every column and the daily information was in columns under each date. The data had to be transposed for every single sheet that came from the MyWell App.

**CONCLUSIONS**

The groundwater explorer is a great way to educate the public about the trends, and patterns of groundwater in these villages and regions. Being able to interact with this data can give users a personal connection to the data. The Well Explorer is a great way to have users feel a personal connection to the people that are actively taking measurements of the well sites and to familiarizing users with the different wells in each region. Making the visualizations more personable is one of the next steps to this project. This will be done by adding pictures of the farmers that own the land that each well is located on. This will be shown on the Well Explorer visualization. The next steps are to evaluate the efficacy of the artifact (Veneable et al., 2016) and based on feedback we will make appropriate modifications. We hope the improved artifacts can help stakeholders, villagers, and other members of the general public use the data to gain an understanding of how rainfall and groundwater levels affect the region that these villages are located in. This can help in better policymaking and resource management in the future.
REFERENCES